MONITORING OF BANK LINE CHANGES USING GEODETIC AND REMOTE TECHNIQUES

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ABSTRACT

The article deals with several ways of monitoring bank line changes, such as the cartographic and two modern satellite-based methods, one of which is the method of satellite images interpretation. It is easy to use and does not need expensive equipment or fieldwork. The second of the satellite-based methods, the field method with the application of satellite positioning system, is characterized by high accuracy and effectiveness of results but requires expensive equipment and fieldworks. The danger of erosion is that main settlements of West Siberian plain are situated along the banks of the rivers. These territories suffer from erosion processes which lead to the decrease in the settlements' areas and causes destruction of residential buildings, cemeteries and farmland. Thus, monitoring of bank line changes is an urgent problem. Erosion and river channel processes, which were examined on the key field testing sites in the middle reach of the river Ob, are subject to a number of general patterns such as spatial and temporal relationships, relation with natural and climatic environments, etc. The key field testing sites correspond to the tectonic faults where the monitoring of the river channel processes has been carried out for 16 years with the help of bench marks on the river cross sections. To perform geodetic measurements two Leica GS10 satellite receivers have been used since 2014. As a result, the lost land area of 842 000 $м^2$ was identified by means of satellite images interpretation. These data are for the time period of 32 years. With the help of satellite equipment it was estimated that in 2015the erosion area was 29 472 $м^2$, in 2016 – 11 403 $м^2$, and in 2017 – 15 400 $м^2$. The obtained data show that the average rates of bank erosion in the river cross sections at the long-term stations are as follows: in 2014 – 2.45 m/ year with the maximum of 13.7 m in cross section10; in 2015 – 5.0 m /year with the maximum of 17m in cross section 10; in 201 – 1.69 m/year with the maximum of 4.04 m; in 2017 – 2.57 m/year with the maximum of 15.4 m in the V^{th} test area. These measurements depend on the climate-hydrological factors.

Keywords: exogenic processes, geomorphic analysis, river channel deformations, lateral erosion, geodetic measurements

INTRODUCTION

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Monitoring of changes and dynamics of erosion processes within the channel and floodplain of large rivers of the West Siberian Plain is an urgent task related to the further forecasting of hazardous natural processes possible in the study area. In their study, the researchers O.V. Korableva and A.V. Chernov have shown the experience of monitoring channel deformations on wide-flooded rivers [1] and estimated the development of rivers, their riverbeds and floodplains.

As the demand for such data increases, old methods of research have to be improved and new ones developed. These methods include monitoring, which is a long-term observation of functions and development of the object under study, held by an unchanged or similar technique at certain intervals [1]. Here we consider several methods of monitoring erosion of the river bank line – the geodetic method and the remote satellite-based method. The methods are similar in the use of satellite data, however, the remote method (deciphering space images) does not require expensive equipment or fieldwork, whereas the geodetic method (geodedic method with the use of satellite positioning systems), being highly accurate and efficient, requires expensive equipment and fieldwork. The results of monitoring river bank lines attest to the severity of erosion. Major regional settlements and industrial facilities associated with oil production are located within the river bank line of the Ob River latitudinal segment, which means these territories are subject to erosion. This decreases the man-used area and leads to emergency situations, as residential buildings and facilities are affected, stability of engineering structures is at hazard, cemeteries are destructed, and agricultural land is reduced. Therefore, monitoring changes of river bank line is an urgent issue.

STUDY AREA

The study considers the Ob River bank line within the city of Nizhnevartovsk and the estuary of the Vakh River. The Ob riverbed of within the study area is developed under active channel deformations. The erosive activity has been observed since 1974, particularly, by Tyumen Complex Geological Exploratory Expedition launched on the right bank of the Vartovskaya Ob channel in Nizhnevartovsk. In 1980, when the city was actively developing, the expedition was moved to the Vakh River estuary and continued its annual estimations until 1994. In 2001, Nizhnevartovsk State University restored the observation at this key field testing site [2]. Located on the right Ob River bank, the site is placed in the wide-flooded area. The river bends are free, segmentally developed with islands in the apical part (branched-sinuous river channel). The bank line deposits are sandy-loamy rocks of lacustrine-alluvial genesis, overlapped by peat as deep as 7m in some areas.

RESEARCH METHODS AND MATERIALS

Intensive channel deformations in the latitudinal part of the middle Ob are quite unfavorable for local economic activity. The issue of safe economic management under lateral erosion is very topical in Russia, particularly, in Western Siberia subject to negative channel deformations [3]. Various types of erosion are formed under natural factors. The latitudinal area of the Ob River includes 11 settlements, 29 licensed oil production sites, and 187 farms. The human economic activity is complicated by erosion occurring as a result of channel deformations, which are hazardous natural processes associated with water streams. As the snow melts in spring, the water level in rivers rises considerably, which leads to the destruction of river bank lines and flooding, with bank erosion being the most prominent process [4]. River bank deformations are caused by erosion-accumulative systems and characterized by the development of watercourse channels depending on the water content of the stream, riverbed parameters and shape, run-off of sediments and other characteristics that allow certain types of channel processes and morphodynamic channel types to be distinguished [5]. Within the long term, uneven horizontal channel deformations depend on the annual water availability and floods. V.V. Surkov in his work gives the data on the shore erosion rates for the Middle Ob – the average of 3-5 m per year and the maximum of 24 m per year [6]. The Ob riverbed below Novosibirsk Hydroelectric Station is more stable: Kc = 4.6-14.5, with 12.2 on average [7]. The research herein is based on the methods developed by R.S. Chalov, A.S. Zavadsky, and A.V. Panin [8]. There is a great number of works concerning the study and forecasting of river channel deformations in Tomsk region, particularly those accumulated by the staff of Tomsk State University Department of Geography and Department of Hydrology. These studies include those started by A.A. Zemtsov, D.A. Burakov in the late 1950-s and later continued by Yu.I. Kamenskov, V.A. Lgotin, N.S. Evseeva, V.S. Khromykh and others [9]. In 1975, O.I. Bazhenova made a report on the development of river bends and modern geomorphological processes in the Middle Ob by comparing pilot charts made in 1928 and 1968 [10]. A large number of studies give the data on the types of rivers, shoreline erosion values, factors of the channel deformation process, and forecasts [11; 12]. In 1976, A.A. Zemtsov predicted that in 20 years the river line near the city of Nizhnevartovsk with be submitted to erosion 200 m wide [12].

The cartographic method is based on obtaining the required data via studying maps. Here, we have analyzed pilot charts, which are maps of rivers, canals and other waterways (the scale is 1: 2000-1: 25000) indicating the banks, current directions, dangerous navigation places and major navigable situation. Pilot charts are the most important documents when it comes to navigation. The information provided on such charts reflect most essential extracts from the current navigation rules, give recommendations and warnings ensuring safe navigation, and other useful navigational descriptions. When studying bank line deformations of large rivers, one should base the research on the use of aerial photographs and topographic maps, since the use of pilot charts, due to their high generalizability, limits the study to tracing only the tendency of erosion to decelerate or intensify. The erosion characteristics estimated from correctly combined pilot charts often differ significantly from those obtained by combining aerial photographs or topographic maps of the same scales. When interpreting space images, one digitizes the bank line reflected in space images using the MapInfo Professional GIS package (licensed for educational institutions). We have used space images made in 1982, 1994, 2001 and 2014 and provided by the Laboratory of Information and Space Technologies of Yugra Research Institute of Information Technologies. Image parameters were as follows: 96 dpi resolution, LZV compression type, color depth of 24, TIFF image format. Further on, we sampled space images for each year, loaded the selected images into the MapInfo program, and loaded coordinate-linked databases (linear hydrography and polygonal hydrography) for mapping satellite images. Then we digitized the surveyed area of the Ob River bank line and calculated the area of the lost territory by creating polygonal objects between digitized lines. Active lateral erosion has been monitored for 16 years with the help of benchmarks anchored on the terrain.

Since 2014, geodetic survey of the studied area has been made with the use of two satellite Leica GS10 receivers. Satellite positioning systems have the following major advantages: globality, efficiency, all-weather capability, optimal accuracy and efficiency. Every year, field work is carried out at the study area, including route work, identification of coordinates, heights of the bank line specific points, analysis of slopes and exposure of the Ob bank line slopes at the site within the erosion area near Nizhnevartovsk. The works duration was estimated from the first captured point to the last. Major equipment used in the survey included Leica GS10 GNSS receivers, AS10 antennas and a controller adjusting the shooting mode settings. Additional equipment included a trigger with the level at which the receiver is mounted on a tripod, a three-meter measuring tape for measuring height, a pole and a rack. During the survey, the correcting station (base receiver) is installed at a point with known coordinates (the point of the state geodetic network); the researcher moves along the specified route with the second mobile (rover) receiver and maps in two modes, static and kinematic. Static positioning is shooting of static objects (base point, control points), with up to 30 min of recording and static shooting mode (for accurate results, the shooting time should be increased as the distance from the research site to the base point increases). Kinematic positioning is used when determining the trajectory of a moving receiver relative to another stationary satellite receiver. Such mode is for determining the coordinates and height of the bank line points, with up to 1 min of recording. The mode requires pressing the START button and pressing it again after the required time (after 1 minute) and moving on. The data obtained via GPS surveys are the main information used for making maps and calculating the area and volume of erosion.

RESULTS AND DISCUSSION

The results of the study are essential for developing integrated engineering measures to strengthen the river bank lines near Nizhnevartovsk and surrounding settlements. Particularly, such measures are a keen concern of the local authorities and are expected with regard to the targeted program 'Transferring citizens from residential buildings located in the flood zone subject to erosion in Nizhnevartovsk district' [13].

The data obtained was processed using LeicaGeoOffice software: SmartWorx raw data files (of .m00 format) were unloaded from the memory cards of the base and rover receivers and loaded into the LGO program. The program processed the data, marked the original data as red and measured data as green. Using 'Process' and 'Save' commands, the data went through final processing to exclude the points with a high geometric inaccuracy. As a result, we received points with coordinates in the LGO program and from there we unloaded the catalog of coordinates in degrees/minutes/ seconds format into Microsoft Excel. Then, to operate in MapInfo, we converted the coordinates into decimal degrees (decimal degrees = degrees + minutes/60 + seconds/3600), imported the resulted data as a catalog of decimal degree coordinates in a 4-column table with the following structure: 1st column – Name, 2nd column – Y, 3rd column – X, 4th column – Year. When importing the catalog into MapInfo we got the geocoded data and built point objects according to the received attribute table. We checked the correctness of reference and location of the constructed points by overlaying spatially interconnected layers and space images and modified the design of the points obtained via 'Symbol style' command. Considering the points obtained, we drew the river bank line using 'Polyline' tool, while keeping the mode of sticking the anchor points with the 'S' key switched on. The procedure was then repeated for each year of the study.

As a result, we received a number of complex primitive elements (polylines) representing river bank lines for each year of measurements. To determine their size, we united the pairs of neighboring polylines, converted the resulting polylines into polygons. Then, using the regionalization procedure, we temporarily combined all the polygons obtained and determined the area subjected to erosion. The following are the data on the average annual retreat of the river bank line according to Tyumen Integrated Hydrogeological and Engineering Geological Compartmented Mode Station: 9.8 m/year in 1983; 4.9 m/year in 1984; 2.76 m/year in 1985; 3.01 m/year in 1986; 3.9 m/year in 1987; 10.42 m/year in 1988; 3.26 m/year in 1989; 7.72 m/year in 1990; 1.54 m/year in 1991; 5.7 m/year in 1992; 4.84 m/year in 1993. Over 11 year, the average annual indicator was 5.26 meters per year [14]. In 2002-2017, the edge of the Ob River bank was displaced with the following annual speed: 7.8 m/year in 2002; 2.35 m/year in 2003; 3.46 m/year in 2004; 2.89 m/year in 2005; 4.19 m/year in 2006; 3.25 m/year in 2007; 1.93 m/year in 2008; 2.36 m/year in 2009; 1.57 m/year in 2010; 1.51 m/year in 2011; 0.68 m/year in 2012; 2.36 m/year in 2013; 2.45 m/year in 2014; 5.0 m/year in 2015; 1.69 m/year 2016; 2.57 m/year in 2017. Over 16 years, the average annual retreat of the bank line amounted to 2.9 m/year, according to observation points. In 2004, the retreat rate of the riverside edge reached its maximum of 17.5 m/year, which corresponds to the data indicated in 'Morphology and Dynamics of the Ob River and the Irtysh River Channels' of Khanty-Mansiysk Autonomous Area-Yugra Atlas (Vol. II, page 75, 2004). Comparing the two observation periods, the activity of bank line erosion from 1983 to 1993 was higher. To verify the obtained values, we compared space images and estimated the areas of lost land over three periods: 416 200 m^2 from 1982 to 1994; 225 000 m^2 from 1994 to 2001; 200 800 m^2 from 2001 to 2014. In 1982-2014 the land area lost as a result of riverside deformations amounted to 842 000 m^2. The analysis showed that the erosion activity of the right Ob River bank in 1982-1994 was higher, which was confirmed by the values obtained during field surveys [2]. To get more detailed data on modern exogenous processes within the period from 2014 to 2016, we applied GNSS geodetic survey and estimated that the erosion area 29.572 m^2 in 2015 was, 11 403 m^2 in 2016, and 15 400 m^2 in 2017, whereas the volume of eroded soil was 144 412.8 m^3 in 2015, with an average bank elevation of 4.9 m; 54 734 m^3 in 2016, with the average bank elevation of 4.8 m; and 81 620 m^3 in 2017, with an average bank elevation of 5.3 m. The obtained data allow making the following estimations: the average riverside erosion at Ust-Vakhsky station was 2.45 m/year in 2014, with the maximum of 13.7 m at section line 10; 5.0 m/year in 2015, with the maximum of 17 m at section line 10 (Figure 2), 1.69 m/year in 2016, with the maximum of 4.04 m; 2.57 m /year in 2017, with a maximum in the control section V of 15.4 m (Figure 3), which is associated with climatic and hydrological factors. We can assume how much the river bank line will change in the future by calculating the average area of the annual erosion. We made a map-scheme of the area under study showing the major control points of the route. The total length of the route from the station base to the first control point is about 5000 m straight and 7000 m along the river bank. The distance from section line 1 to section line 10 is 3792 m. To find the volume of eroded soil, one required area and height values. We received the data on the height of the river bank elevation in 1984 from the Topographical base of Nizhnevartovsk Engineering Geological Section, based on a topographic survey performed that year, and for the period from 2005 to 2017 the data was extracted from the measurements taken via a morphometric method by Nizhnevartovsk State University Laboratory for Geoecological Research on an annual basis. The method is based on the direct measurement of the terrain lines by mechanical linear devices, including measuring tapes and roulettes, sequentially positioned in the section line. All the data obtained were systematized and collected in a table used to calculate the volume of the eroded soil. As a result, we can predict the channel deformation in this area, with the maximum possible linear erosion from 17 to 25 m/year and average erosion from 3 to 5 m/year. This means that the maximum area erosion can be in the range from 65 000 to 95 000 m^2 and the maximum eroded soil volume can amount to 300 000-500 000 m^3. The average area erosion can vary from 10 000 to 30 000 m^2, while the average volume can amount to 54 000- 145 000 m^3. In Nizhnevartovsk region, the segment of the Ob River floodplain-terrace, meadow-bog-forest area amounts to 9709 km^2, while 88% of the territory is occupied by licensed oil production sites. The maximum danger of erosion processes is manifested when the flooding reaches the level of 40 m, which happens every 28 years. In such situation, the width of the flooded area varies from 5 to 68 km, the length amount to 199 km, the flooded territory area reaches 5588 km^2. The share of licensed oil production site is 4,463 km^2, which is 79% of the flooded area [15]. The flooded zone includes such cities, towns and settlements as Nizhnevartovsk, Langepas, Megion, Vata, Pokur, Bylno, Pasol, Zaitseva Rechka, Vampugol, and Sosnino.

CONCLUSIONS

The cartographic method allows us tracing the tendency to erosion only. When using the method of space image interpretation, we have estimated the land area lost due to channel deformations, which amounted to 842 000 m^2 over 32 years. Considering low resolution of space images, this method can only be applied for determining the areas with a tendency to erosion and making approximate estimations. With the use of satellite equipment, the coordinates of the bank line points, their height, channel deformations for each section line and the total erosion area were determined. After processing and unifying the data, we estimated that over 35 years the erosion area at Ust-Vakhsky key field testing site amounted to 898 275 m^2, with the total eroded soil volume of 4 858 345 m^3.

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